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RELATED PCT APPLICATION NUMBER: *PCT/US03/07123*

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PROVISIONAL APPLICATION FOR PATENT COVER SHEET

This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53(c).

Express Mail Label No. ET909222239US

INVENTOR(S)

Given Name (first and middle [if any])	Family Name or Surname	Residence (City and either State or Foreign Country)
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☐ Additional inventors are being named on the _______ separately numbered sheets attached hereto

TITLE OF THE INVENTION (500 characters max)

METHOD FOR LINEARIZING DEFLECTION OF A MEMS DEVICE USING BINARY ELECTRODES AND VOLTAGE MODULATION

CORRESPONDENCE ADDRESS

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ENCLOSED APPLICATION PARTS (check all that apply)

☑ Specification Number of Pages 6
☐ CD(s), Number
☐ Drawing(s) Number of Sheets
☐ Other (specify)
☐ Application Data Sheet. See 37 CFR 1.76

METHOD OF PAYMENT OF FILING FEES FOR THIS PROVISIONAL APPLICATION FOR PATENT

☑ Applicant claims small entity status. See 37 CFR 1.27.
☐ A check or money order is enclosed to cover the filing fees
☑ The Commissioner is hereby authorized to charge filing fees or credit any overpayment to Deposit Account Number: 023255
☐ Payment by credit card. Form PTO-2038 is attached.

FILING FEE AMOUNT ($) $80.00

The invention was made by an agency of the United States Government or under a contract with an agency of the United States Government.
☐ No.
☐ Yes, the name of the U.S. Government agency and the Government contract number are: ____________

Respectfully submitted,

SIGNATURE [signature]

Date 03/08/2002

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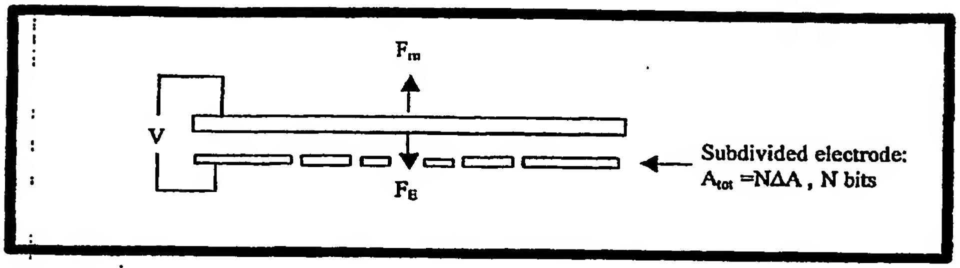
Docket Number: BU02-15

USE ONLY FOR FILING A PROVISIONAL APPLICATION FOR PATENT

User name is not in the list

Notes on Multi-Electrode System
28 November 2001



Governing Equations

$$F_m = \frac{192EIx}{L^3}$$ Mechanical restoring force for a given displacement, x

$$F_E = \frac{\varepsilon A V^2}{2(g-x)^2}$$ Electrostatic Force

Equilibrium occurs when $F_m = F_E$:

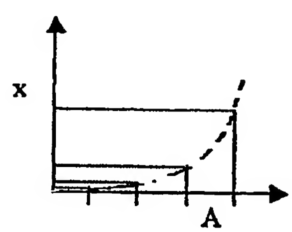
$$A = \frac{C}{V^2}x(g-x)^2 = \frac{C}{V^2}[x^3 - 2gx^2 + g^2x]$$

where,

$$C = \frac{384EI}{L^3\varepsilon}$$

Problem:

Deflection, "x", is a strongly non-linear function of area, "A". Therefore, actuation approach based on fixed voltage and uniform increments in A will not lead to uniform increments in phase.



Mathematically:

$$A=\frac{C}{V^2}x(g-x)^2=\frac{C}{V^2}[x^3-2gx^2+g^2x]$$

$$\frac{dA}{dx}=\frac{C}{V^2}[3x^2-4gx+g^2]$$

so: $$\frac{dx}{dA}=\frac{V^2}{C[3x^2-4gx+g^2]}$$

An estimate of the largest step in "x" made by uniformly increasing "A" is:

$$\Delta x_m \doteq \left.\frac{dx}{dA}\right|_{x_m}\cdot \Delta A$$

where x_m in the maximum required value of x; Δx_m in the maximum x step.

But: $\Delta A=\dfrac{A_{tot}}{2^n-1}$ by design

And $A_{tot}=\dfrac{C}{V^2}x_m(g-x_m)^2$ by model

therfore

$$\Delta x_m=\frac{V^2Cx_m(g-x_m)^2}{CV^2[2^n-1][3x_m{}^2-4gx_m+g^2]}$$

simplifying:

$$\frac{x_m}{\Delta x_m}=\frac{(2^n-1)(g-3x_m)}{(g-x_m)}$$

The resolution of the actuator can be defined as one part in M, where

$$M=\frac{x_m}{\Delta x_m}$$

$$\therefore M=\left(\frac{g-3x_m}{g-x_m}\right)(2^n-1)$$

Non-linearity is worst for $g = 3x_m$, and improves as g increases.

Example:

$g = 3.1x_m$

$$M = \left(\frac{0.1}{2.1}\right)(2^n - 1)$$

Factor of 20+ loss of resolution (e.g. 8 bit system provides ~3 bit resolution)

Resolution Reduction Factor, R is:

$$\frac{1}{R} \equiv \left(\frac{g - 3x_m}{g - x_m}\right)$$

Improvement in resolution is possible, by increasing "g".

g	R	
$3.1x_m$	21	*(~silicon single-gap structures)*
$4x_m$	3	
$5x_m$	2	*if $g >= 5x_m$, only 1 bit of resolution is lost*
$6.7x_m$	1.5	*silicon double-gap structures*

Price: Increase driving voltage

$$V^2 = \frac{C}{A} x (g - x)^2$$

therefore:

$$\left(\frac{V_2}{V_1}\right)^2 = \frac{C/_A\, x_m (g_m - x_m)^2}{C/_A\, xm (g_m - x_m)^2}$$

and

$$\frac{V_2}{V_1} = \frac{g_2 - x_2}{g_1 - x_1}$$

is the ratio of maximum required voltages for two different gaps. C,A, and x_m unchanged.

If $g_2 = 5x_m$, and $g_1 = 3x_m$,

$V_2 = 2V_1$

Alternative solution: Linearize

$AV^2 = Cx(g-x)^2$

this could be linearized by imposing the constraint that:

$V^2 \propto (g-x)^2$ or $V = k(g-x)$

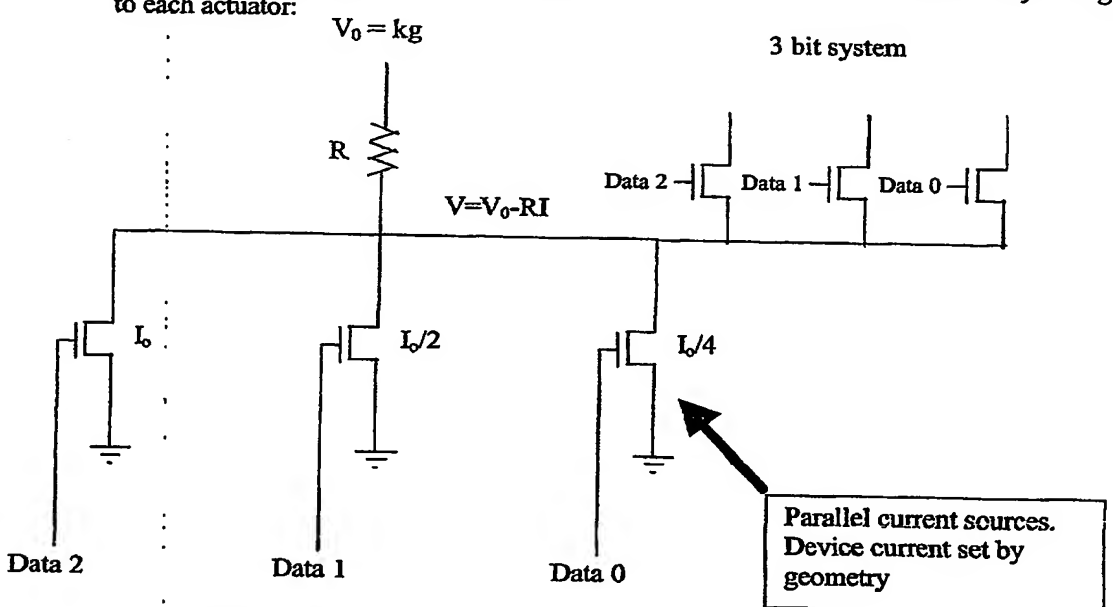
then $A = \frac{C}{k^2}x$

find value of k:

$A_{tot} = \frac{C}{k^2}x_m \qquad k = \sqrt{\frac{Cx_m}{A_{tot}}}$

For the silicon structures with a 2.5 μm gap: V_r ~ 70V and V_f ~ 50V

How to make $V = k(g-x)$?
Input to system (binary) is a linear representation of x. Use the data bus to modify voltage to each actuator:

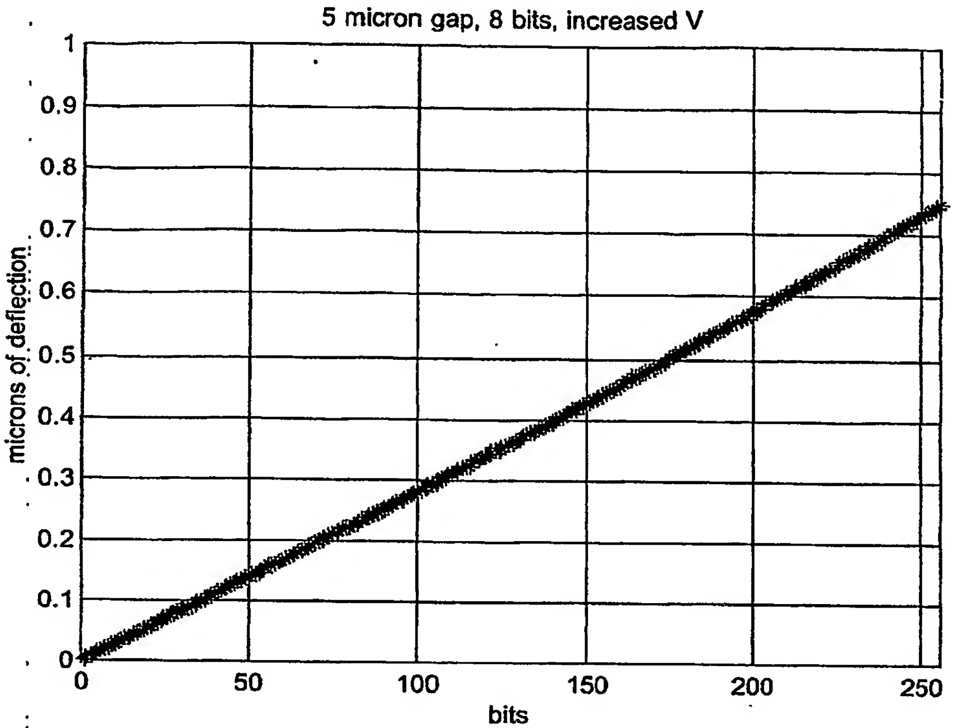


Solution developed by Mark Horenstein

1-15-2002

Best Available Copy

Model of an 8 bit system, with a 5 μm gap using the linearized voltage solution (V_t = 130V)



```
%--MATLAB PROGRAM--
%Example of linearizing the deflection versus digital input curve.
%Requires that the voltage applied to the electrodes be reduced as
%the digital input n goes up from 0 to N (where N = 16, 128, 256, etc)
close; clear;                                   %close any previous plots and reset
variables
N=256;                                                  %Maximum value of digital
input 2^n where n=0...N (8 bits in this example)
k = 60;                                                 %elastic restoring force in
N/m (typical)
eo = 8.85e-12;                                  %electric permittivity of air
side = 250e-6;                                  %dimension of each side of actuator
Area = side^2;                                  %total area of actuator
Ao=Area/N;                                              %smallest increment of area
(area increment per digital bit)
gap = 5e-6;                                     %spacing between actuator and
activation electrode
dy = gap/1000;                                  %incremental deflection to be used
in iteration

for n=1:N;                                              %Plot y versus digital input
n for n=1...N:
   V=40*(1-n/(8*N));        %V is a function of n. Equal to 40 V at start, decreases
                                                           %in a straight line
function with n. I think we can do this
                           %in a straightforward manner electronically in VLSI.

%----Iteration to solve for deflection y as a function of digital input n -----
y=0;                                          %initialize deflection to zero
Fm = k*y;                                               %Compute magnitude of
mechanical force
Fe = eo*Ao*n*V^2/(2*(gap-y)^2);               %Compute magnitude of electrostatic force

       %(Total area is n times Ao)
%-----------------------------------------------------------
while Fm < Fe;
            y = y + dy;                                 %Try a slightly larger
deflection
            Fm = k*y;                               %Recompute magnitude of
mechanical force
      Fe = eo*Ao*n*V^2/(gap-y)^2;             %Recompute magnitude of electrostatic force
                                                                                  %Get
out of loop when Fm = Fe.
end
Y(n)=y;                                                 %Save this value of y(n) for
later plotting
end                                                           %Iterate over all
values of n from 0...N
%Done with iteration
plot(Y*1e6)                                             %Plot deflection in microns
versus n

%Suggestions variations on the program:

%Set V to a fixed 40 V; this change will demonstrate non-linearity in area vs n
curve.
%Set V to 40(n/N) and change Ao*n to Area; this change produces the usual nonlinear
%deflection versus voltage curve.
```